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DYNAMIC RESPONSE ANALYSIS OF COMPOSITE STRUCTURAL MEMBERS DURING MISSILE LAUNCH

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Abstract: By analyzing the dynamic characteristics and the dynamic response of composite structural members of aircraft wings, the article presents the methods and steps for computational analysis, as well as further processing of the analytical results, in addition to suggestions for design improvements. It was found that improved lamina design can eliminate design weakness since local vibration phenomena were discovered in the prototype design when the dynamic characteristics of structural members were analyzed. By comparing three computational missile launch variants for outboard wing, mid-wing, and inner wing, the values of the dynamic response in the most serious situation are given. Finally, the dynamic strength is determined.

Key words: Composites, vibrational mode, dynamic response, dynamic strength.

The dynamic-mode design of composite structural members should begin with an analysis of lamina design of the composite

materials in making analyses of the dynamic characteristics and dynamic response of structural members; finally, the necessary finding of dynamic strength is given. When analyzing dynamic characteristics, it should be noted that local vibration characteristics of structural materials should be investigated in order to improve the design parameters of the weak components and sites in order to realize the optimal structural design.

I. Lamina Analysis of Composite Lamina Pressed Plates

For a dynamic analysis of composite structural members, one must establish a computational model of finite element analysis. Thus, it is required to make a lamina analysis of composite lamina plates in order to provide related characteristic parameters of a single element in the computational model.

Nine kinds of lamina plate designs are selected for composite aircraft wings for laying out 21 to 51 laminas. By using the lamina analysis program GENLAM, the following stiffness characteristics of various laminas in a plate are obtained in terms of the lamina angles and lamina order of various lamina plates: E_1, E_2, E_6, v_{21}, v_{12} and v_{16}. Next, these characteristics are placed in the elasticity matrix C of the various laminas.

$$C=\begin{bmatrix} C_{xx} & C_{xy} & C_{xs} \\ C_{yx} & C_{yy} & C_{ys} \\ C_{sx} & C_{sy} & G_{xy} \end{bmatrix}=\begin{bmatrix} E_1 & E_2 v_{21} & E_6 v_{61} \\ E_1 v_{12} & E_2 & E_6 v_{62} \\ E_1 v_{16} & E_2 v_{26} & E_6 \end{bmatrix}$$

The values of the elasticity matrix C of all the laminas are listed in Table 1.

TABLE 1. Material Characteristics (GPa) of Plate Elements

* 材料号	C_{xx}	C_{xy}	C_{xs}	C_{yy}	C_{ys}	G_{xy}
1	52.0508	10.5094	−4.3880	47.3686	−5.7408	15.1977
2	46.9742	13.1013	−4.7961	43.8409	−4.2046	18.2897
3	56.6370	15.0887	0.0	31.9345	0.0	20.6167
4	52.8906	15.8991	0.0	33.8533	0.0	21.2131
5	45.0681	16.8820	0.0	31.4097	0.0	23.8383
6	48.1985	16.5897	0.0	32.1689	0.0	22.8631
7	41.8083	17.0665	0.0	32.5819	0.0	24.4053
8	51.2150	15.2732	0.0	40.3613	0.0	20.0173
9	42.2742	17.05765	0.0	30.40125	0.0	24.7457

KEY: * Material number

II. Analysis of Dynamic Characteristics of Composite Structural Members

Under conditions when missiles were suspended from the composite aircraft wing, the dynamic characteristics were calculated for three cases: mid-wing missile suspension site (case 1), outboard-wing missile suspension site (case 2), and all missiles suspended at mid-wing and outboard wing (case 3). Altogether, 469 plate shell elements and 729 member elements are included in the computational model; the overall equation has 1909 orders. All the computational results are listed in Table 2.

In Table 2, the first ten orders of vibration frequencies of the three computational cases are given; in the last line, the first two orders of vibrational frequency, when adopting an all-

metal structure, are given. By referring to Table 9, we see that with an increase in outboard suspension, the low order frequencies become smaller. However, the values of the low order frequencies of composite structural members are higher than for metal structural members. In the case of no outboard-wing missile suspension, the low order frequencies are also lower than those for composite wings with outboard missile suspension site. Therefore, the composite aircraft wing proves to be successful in layout design. As for the local vibrational phenomena showing up in the prototype design, these phenomena can be eliminated after lamina design improvements.

TABLE 2. Values of Intrinsic Characteristics (Hz) of Three Missile Suspension Site Configurations

a 挂弹方案	情况 I m	情况 II n	情况 III o
b 1阶频率	1.4588E+01	1.4994E+01	1.1393E+01
c 2阶频率	2.2938E+01	3.4204E+01	2.2002E+01
d 3阶频率	4.5957E+01	5.2758E+01	4.0894E+01
e 4阶频率	6.5895E+01	6.0771E+01	4.9117E+01
f 5阶频率	7.1844E+01	8.2021E+01	7.1082E+01
g 6阶频率	9.1827E+01	9.6290E+01	7.2253E+01
h 7阶频率	9.6325E+01	1.1493E+02	9.0520E+01
i 8阶频率	1.0901E+02	1.2174E+02	9.6333E+01
j 9阶频率	1.1132E+02	1.3057E+02	9.6673E+01
k 10阶频率	1.3148E+02	1.3714E+02	1.2944E+02
l 金属结构	b 一阶频率 = 1.0542E1 c 二阶频率 = 2.5824E1		

KEY: a - Missile suspension site configuration b - First order frequency c - Second order frequency d - Third order frequency e - Fourth order frequency f - Fifth order frequency g - Sixth order frequency h - Seventh order frequency i - Eighth order frequency j - Ninth order frequency k - Tenth order frequency l - Metal structure m - Case 1 n - Case 2 o - Case 3

III. Dynamic Response Analysis of Composite Structural Members

This response computation is conducted on the impact load when a missile is launched from an aircraft wing. By using the previous computational results of dynamic characteristics, one reiterates the computation, thus obtaining the dynamic response for various missile cases, from inner wing, mid-wing, and outboard wing, as shown in Fig. 1.

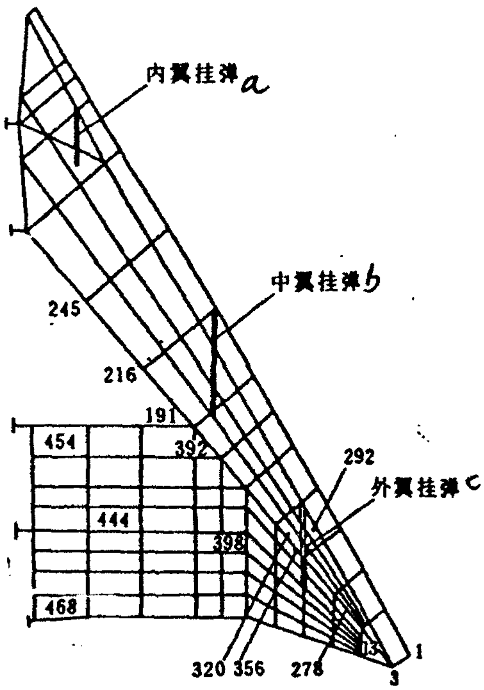

Fig. 1. Configurations of missile suspension from aircraft wing
KEY: a - Missile suspension from inner wing b - Missile suspension from mid-wing
c - Missile suspension from outboard wing

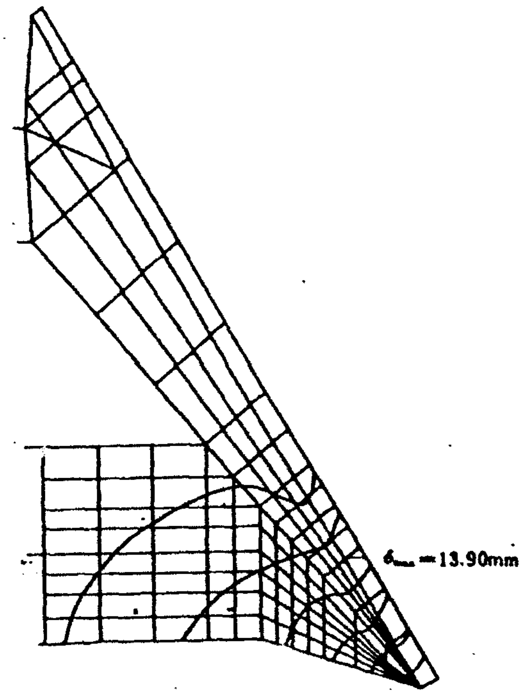

Fig. 2. Displacement distribution when missile is launched from outboard wing

Damping of the structural systems has very important effects on the dynamic response of a structural member. Since the response analysis is impact response of the typical triangular loading, and the stress zone of the response is concentrated mainly in the vicinity of the loading action points, the effects of structural loading are thus neglected. Of course, this treatment is conservative.

By comparing three response cases during a missile launch, we found the displacement response to be the most serious when a missile is launched from the outboard wing. Since the displacement response of various nodal points is a process curve of displacement time, to uniformly express the situation of maximum response displacement, the maximum response displacement of stress concentrations at different times can be expressed. At 0.38 second, the maximum displacement of the wing tip site is 13.9 cm. The distribution of response displacements of the entire structure can be expressed in a cloudlike map or isopleths. At a certain time value, the equal displacement curve graph can be plotted by using the displacement value at various points. Fig. 2 shows the distribution of displacement isopleths for the case when a missile is launched from the outboard wing.

The stress analysis of the overall structure is also computed with respect to various launch cases. As there are different sites of loading function in the various cases, there are different high stress zones that are generated.

For stress analysis of plate elements, an isopleth diagram of 29 stress parameters can be plotted, including diaphragm stress, bending stress, resultant stress, principal stress, and Von Mises stress. Figs. 3 and 4 show the equal-stress curves of σ_2 for a missile launched from the outboard wing and σ_1 for a missile launched from the inner wing. It appears that all high stresses are concentrated in the zone near the missile suspension site.

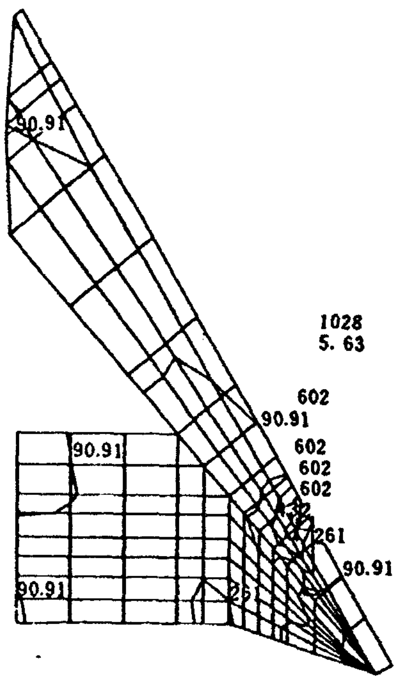

Fig. 3. Stress distribution for case when missile is launched from outboard wing

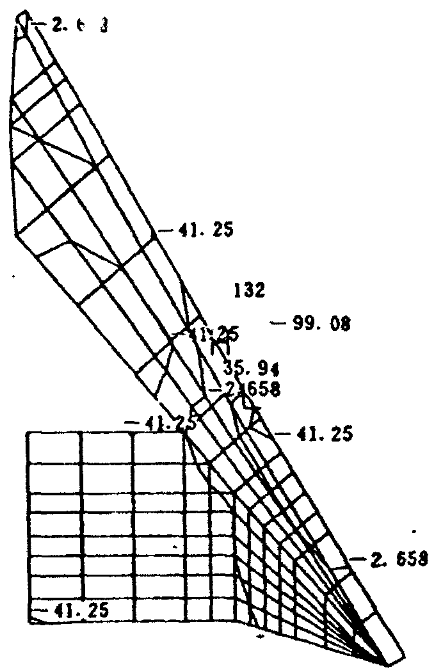

Fig. 4. Stress distribution for case when missile is launched from inner wing

IV. Discussion

Since the allowable operating stress and allowable design stress in composite structural members are determined by the lamina situation in a lamina plate, nine lamina plates of this

aircraft wing structure have nine sets of different allowable operating stress and allowable design stress. Under the condition that fatigue service life is not considered, the criterion of the simplest static strength is compared with the maximum stress of the dynamic response. Thus, all elements with the highest stress levels in the various laminas are selected for a comparison with the allowable design stress in the various lamina plates; thus, the final dynamic strength is derived.

Table 3 shows the number of plate elements and the various stress components with the highest dynamic stress levels in various lamina plates.

TABLE 3. Maximum Stress Levels (MPa) in Various Lamina Plates

层压板 a	单元号 b	σ_1	σ_2	τ_{12}
1	292	133.15	41.28	26.66
2	320	185.28	69.39	36.18
3	278	86.57	18.96	33.17
4	468	110.70	81.98	76.09
5	392	100.87	[illegible].82	165.81
6	356	159.35	51.23	60.14
7	398	79.22	39.94	116.52
8	444	73.13	52.67	93.52
9	454	51.95	60.95	74.24

KEY: a - Lamina plate b - Number of elements

In Table 3, all stress levels of various elements lie within the allowable design stress of the various lamina plates; Fig. 1 shows the positions of various elements. The highest stress level is at the Number 392 plate element of the Number 5 lamina plate, approaching the allowable operating stress for that

particular lamina plate: $\sigma_1'' = 185.31\text{MPa}$, $\sigma_2'' = 89.74\text{MPa}$, $\tau_{12}'' = 112.45\text{MPa}$. However, these are still lower than the allowable design stress: $\sigma_1'' = 476.47\text{MPa}$, $\sigma_2'' = 243.95\text{MPa}$, $\tau_{12}'' = 305.49\text{MPa}$.

Conclusions: all the composite lamina plates of these composite structural members satisfy the requirement of dynamic strength for missile launch from inner wing, mid-wing, and outboard wing.

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